Journal of Applied Ichthyology

J. Appl. Ichthyol. 27 (2011), 405–410

ISSN 0175–8659

Received: August 12, 2010
Accepted: January 25, 2011
doi: 10.1111/j.1439-0426.2011.01727.x

Management of the Lake Sturgeon *Acipenser fulvescens* population in the lower St Lawrence River (Québec, Canada) from the 1910s to the present

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Summary

The main objective of this paper is to show that a well-managed lake sturgeon *Acipenser fulvescens* population can support a high and sustainable commercial catch, even in the Great Lakes drainage where the species has nowadays become rare. In a 350-km long un-fragmented stretch of the lower St Lawrence River located between Montreal and downstream Quebec City, with declared annual catches of 150 tonnes, the lake sturgeon population was considered overexploited by a governmental scientific committee in 1987 on the basis of high annual mortality rates (17–25% for age groups 14–31), unbalanced age structure, deficit of reproductive potential and commercial catch yields well over 1.5 kg ka^{-1}. A first management plan implemented in 1987 failed to reduce the catch and provide more protection to the spawning stock. During the 1990s, the declared catch of the 76 commercial fishermen kept increasing over 200 tonnes. The age at the recruitment of the 20-cm-mesh gill-nets shifted towards older fish, indicating a decrease in the numbers of younger fish. In the population, sub-adult abundance decreased by 60%, as well as the year-class strength and the abundance of the females on the largest known spawning ground. In 2000, a stronger management plan was then enforced in order to adapt the total catch to the potential of the resource. The commercial catch was reduced by 60% in 3 years and an individual code-bar plastic tag and a code-bar weight declaration coupon were established to control its application. The fishing season was also shortened. Ten years later, we are confident in maintaining the actual commercial fishery because the commercial catch is now much lower (80 tonnes) and is more effectively controlled, the abundance of juvenile lake sturgeon increased throughout the St Lawrence River and the regular yearly production of cohorts has been demonstrated. Restrictive management measures, close supervision of landings combined with periodic monitoring of the population are key elements in managing this long-lived species. We also emphasize the importance of preventing any further fragmentation of this portion of 350 km of fluvial habitat as well as to maintain habitat quality to ensure the sustainability of this fishery.

Introduction

When the first Europeans began to actively settle North America, about 400 years ago, the lake sturgeon was the subject of great veneration and respect by the First Nations. This fish was abundant and very large specimens were common throughout the 250 000 km^2 Great Lakes–St Lawrence River drainage basin. Some Algonquin bands were even nicknamed 'The Sturgeons' (Mélançon, 2006) and the Abenakis used a sturgeon-shaped drawing to sign treaties with the Europeans. By the early 1900s, at the end of the Industrial Revolution and <15 human or sturgeon generations later, the species has become rare in the Great Lakes. Population decline has been attributed to a combination of overfishing and large-scale habitat destruction as a result of the many sawmills and dams erected on the main rivers used for spawning. In 2006, lake sturgeon was identified as a threatened species in the Great Lakes-Upper St Lawrence River by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC., 2006).

This species occurs all along the Québec portion of the St Lawrence River, where it now forms two populations. The first, located in Lac St-François, has been gradually separated from the downstream and upstream groups by the construction of the Beauharnois–Les Cèdres (1912–1961) and Moses-Saunders (1958) hydropower complexes. Tagging studies in the 1940s (Roussow, 1955) indicated that the lake sturgeon was able to migrate up the St Lawrence River from the limits of the brackish waters at least as far as the outlet of Lake Ontario. Recent scientific surveys by the Ministère des Ressources naturelles et de la Faune du Québec and by the Ontario Ministry of Natural Resources confirm that the Lac St-François sturgeon population, considered depleted in the 1940s (Cuerrier and Roussow, 1951), the 1960s (Joliff and Eckert, 1971) and the 1980s (Dumont et al., 1987a), is still very sparse. Depletion of the Lac St-François sturgeon population can likely be related to the combined effects of the gradual construction of dams at both extremities of the lake between 1912 and 1961 (Morin and Leclerc, 1998) and the overfishing of the remaining stocks (Dumont et al., 1987a). Sturgeon fishing in this area has been prohibited since 1987.

The second population exists in a 350-km long stretch of the St Lawrence River downstream of Lac St-François, from Beauharnois dam to the brackish waters downstream of Québec City. This population is considered a homogeneous phenotypic and genotypic stock (Guénette et al., 1993). In this 350-km non-fragmented stretch, the lake sturgeon has also been affected by anthropogenic pressure but evidently to a lesser extent than the Great Lakes populations. In this paper, we show that the lower St Lawrence River lake sturgeon population, considered overexploited in the 1980s, recovered due to the enforcement of a strong management plan designed in 2000. This second plan was designed to adapt the total catch to the potential of the resource, after the failure of a first management plan implemented in 1987. We also suggest that,

although it may be too early to state definitely, this lake sturgeon population improved recently and that the 2000 management plan is working to maintain the current commercial fishery. We finally emphasize the key elements in managing this long-lived species and the need to maintain habitat quality to ensure the sustainability of this fishery.

Study area

The St Lawrence River, which flows from the Great Lakes to the Atlantic Ocean, is one of the largest rivers in North America (Fig. 1). The river system extends more than 1500 km and comprises three fluvial lakes connected with lotic sections, a freshwater estuary, a brackish-water estuary and a marine estuary flowing into the Gulf of St Lawrence and the Atlantic Ocean. The river is composed of several water masses, originating from different tributaries which vary in flow rate and concentration of dissolved and particulate organic and inorganic suspended matter (Frenette and Vincent, 2003). The average flow at Québec City is 12 600 $m^3 s^{-1}$, mainly originating from the Great Lakes. From Lake Ontario to the lower estuary, three main types of modification, including dam construction, channeling and flow regulation, have resulted in gradual changes to the lower part of the watershed over the last 150 years. Additional major disturbances occurred during the 1900s with industrial, urban and agricultural development. Commercial lake sturgeon fishing takes place in the lower portion of the system, from Beauharnois dam to the freshwater limit downstream of Québec City. The fishery is concentrated in three main sectors: Lac St-Louis, Lac St-Pierre and the upper estuary (Fig. 1). Lake sturgeon sportfishing is of little importance in this area.

Material and methods

This review is based on a series of biological surveys conducted since the early 1980s which monitored the temporal and spatial evolution of various indicators of abundance, as well as the age and size structure of the lake sturgeon stocks in the St Lawrence River. The data gathered and analyzed cover different segments of the population: juveniles, sampled by means of experimental fishing, and sub-adults and adults, captured through experimental fishing and the commercial fishery.

The commercial fishery was monitored through daily landings declared by commercial fishermen and periodic characterizations of the catch structure on the fishing boats as the nets were hauled in. In the 1980s and 1990s, this monitoring was conducted twice in two of the three commercial fishery sectors (Lac St-Pierre and the upper estuary) and three times in Lac St-Louis. The operation was repeated in the same three sectors in 2004. These results allowed for an evaluation of relative abundance (based on landings in terms of number and biomass per unit effort, size and age breakdown), male / female ratio and the proportion of sexually mature specimens. The annual total mortality rate was estimated from the catch curve (Ricker, 1975) after correction for mesh size selectivity, using the selectivity coefficients of Fortin et al. (1992, Appendix 1, 203-mm mesh, commercial fishing net).

Recruitment monitoring began in 1991 (Nilo et al., 1997) to compensate for the approximate 15 to 20-year lag between the birth of a cohort and its first appearance in commercial fishing catches. The evaluation of the annual relative year-class strength index is based on the age distribution of sturgeon caught in experimental multi-mesh nets during three 1-week sampling periods (June, July and August–September) in an area that is highly frequented by the juvenile segment of the population (i.e. the St-Pierre archipelago). The methodology used for sampling, age determination and calculation of the year-class strength index is described in Dumont et al. (2011).

The relative abundance, in numbers and mass, of the juvenile and sub-adult segment of the population was estimated as part of periodic monitoring of fish communities in the St Lawrence River (La Violette et al., 2003). Since 1995, sampling has been conducted at 617 stations distributed

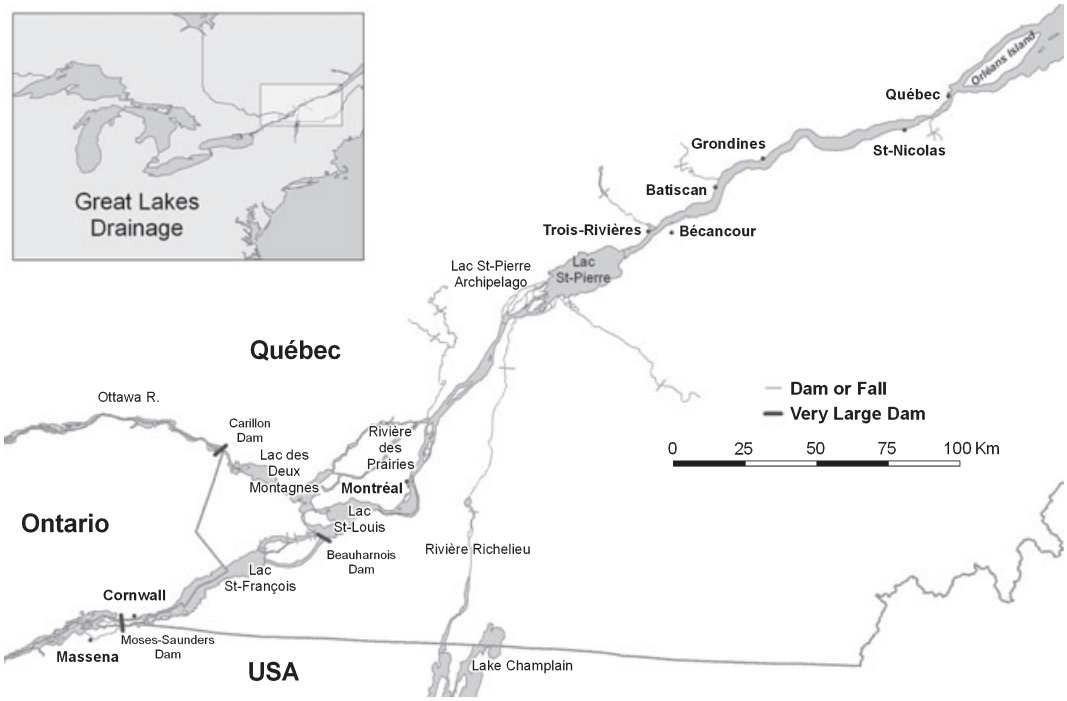

Fig. 1. Major Habitats of Lake Sturgeon Populations in the Québec Portion of the St Lawrence River System

systematically over Lac St-Louis, the channels of the Lac St-Pierre archipelago, Lac St-Pierre and the upper estuary. Sampling was conducted using gill nets over an approximately 24-h period during late summer and early fall. Gill nets were 1.8 m high by 7.6 m long and consisted of eight panels of mesh (25, 38, 51, 64, 76, 102, 127 and 152-mm stretched mesh). A detailed description of the sampling strategy and the methods used is provided in La Violette et al. (2003). All of the sturgeons caught were measured (total length) before being released. Weights were estimated on the basis of the weight-total length relationship established by Fortin et al. (1992) for the St Lawrence River. For each sector, the average catches, in terms of number and mass, were compared statistically between sampling years using the nonparametric Kruskal–Wallis test; the proportions of stations with and without sturgeon catches were determined by chi-square tests. Statistical processing was performed using JMP®; SAS Institute Inc. software, version 3.2.1 (Sall and Lehman, 1996).

Results

Lake sturgeon population evolution and harvesting in the St Lawrence River

During the early settlement period along the lower St Lawrence River, lake sturgeon populations were considered to be very healthy. In 1664, Pierre Boucher, French governor of Trois-Rivières, reported that the lake sturgeon was very abundant upstream of Québec City, especially in all the St Lawrence fluvial lakes and at the present site of Montréal (Boucher, 1664). Further, Boucher (1664) reported that some of these fish were very large, from 1.3 to 2.5 m long. Efforts to conserve the lake sturgeon appear early on in the available historical sources. For instance, in the 1910s, Québec sport fishing rules imposed a closure period in June that was also likely applied to commercial fishing. A commercial minimum size of 45 cm of dressed length (approximately 80 cm total length) was enforced in the 1940s and might even have been implemented earlier, in 1927. Since the mid-1900s, following post-World War II industrialization, other pressures including: chemical and sewage pollution, additional dams construction, massive mortalities caused by an episode of large-scale spreading of pesticides or 'accidental' outflows of toxic effluents, dredging and dumping operations conducted for channel and harbor maintenance, continuous extensive commercial fishing and poaching on every major known spawning ground have impacted the St Lawrence River lake sturgeon population. These numerous combined pressures have dramatically reduced the biological potential of this species in large subsystems such as the Ottawa River (Haxton and Findlay, 2008), Lac Des Deux-Montagnes (Fortin et al., 1993) and Lac St-François (Dumont et al., 1987a).

1987: A diagnosis of overfishing and an initial management plan

With declared annual catches in excess of 150 tonnes in the 1980s and 200 tonnes in the 1990s (Fig. 2), and annual yields well over 1.5 kg ha^{-1}, the lower St Lawrence River lake sturgeon commercial fishery was one of the most important sturgeon fisheries in North America (Dumont et al., 1987a). The sturgeon population between Montréal and downstream of Québec City was deemed to be overfished by a governmental scientific committee in 1987, on the basis of high annual mortality rates (17–25% for age groups 14–31), unbalanced age structure, deficit of reproductive potential and excessive catch yields (Dumont et al., 1987b). Poaching was still important and widespread, as stated by commercial fishermen themselves (APCLSP (Association des Pêcheurs Commerciaux du Lac Saint-Pierre), 1987), and many admitted in private that the abundance of the fish and the proportion of large specimens were much lower than before. Three main factors were then identified as likely accounting for the high resilience of this stock: (i) the relatively high productivity of the system, (ii) the fact that intensive commercial fishing was restricted to specific zones, leaving some sectors to act as reservoirs (this 'sanctuary' effect is undoubtedly important), and (iii) the high selectivity of the commercial gill nets (19 to 20-cm stretch mesh) historically used.

A management plan was implemented in 1987 (Ministère du Loisir, de la Chasse et de la Pêche, 1987) to reduce the catch and to provide more protection to the spawning stocks. The management plan worked to shorten the commercial fishing season, reduce the number of fishing licences and the sport bag limit, eliminated the use of a longline – a type of gear that favored the capture of large specimens – gill net mesh size was

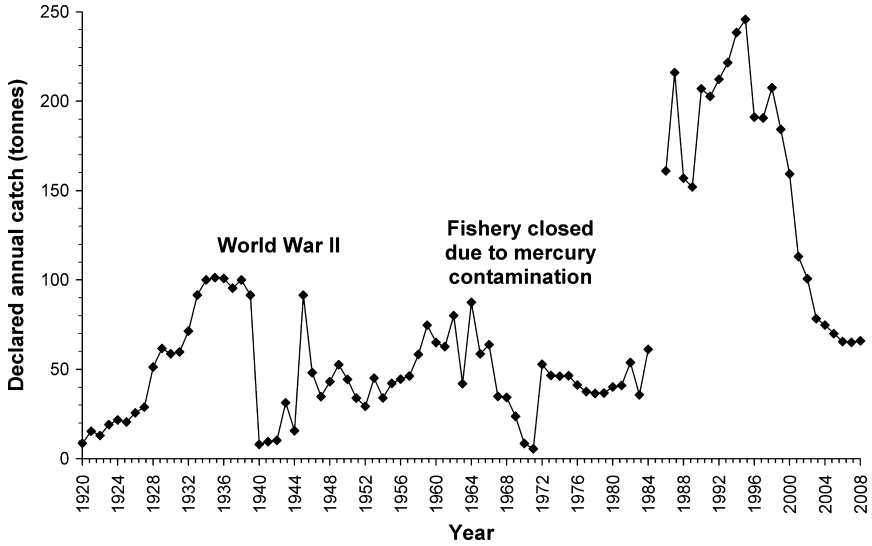

Fig. 2. Declared Lake Sturgeon Commercial Landings in the Québec Portion of the St Lawrence River 1920–2008 (Data from Robitaille et al. (1988), ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, ministère des Ressources naturelles et de la Faune du Québec)

restricted to 20 cm stretched and law enforcement was strengthened. During this period, biological knowledge of reproduction, early life history, juvenile development and habitat was also enhanced by a cooperative effort involving governments, universities and hydroelectric utilities.

1998: Failure of the 1987 management plan

From the mid-1980s to the mid-1990s, in spite of the restrictive measures applied in the 1987 management plan, the total declared catch of the 76 commercial fishermen increased to over 250 tonnes (Fig. 2). In 1994, results of sampling of the harvested segment in the four major commercial fishing areas showed that 10 years after the studies of the mid-1980s, annual mortality rates had remained high and that the age at recruitment to the 20-cm-mesh gill nets had shifted towards older fish, indicating a decrease in the numbers of younger fish (Dumont et al., 2000a). This study also determined that the sturgeons were spread in the river along a size gradient, with the smallest and youngest specimens being located farther downstream from the spawning grounds. As these fish become sexually mature, it is thought they move upstream towards Montréal (Fig. 3).

Moreover, studies conducted between 1994 and 1999 showed a 60% decrease in subadult stock abundance and in year-class strength between 1984 and 1992 in the population (Dumont et al., 2000a). A 60% decrease in abundance of females was also measured from 1995 to 1999 in the Rivière des Prairies spawning ground, the largest known of the system (Dumont et al., 2011). The commercial catch however continued to increase during this time (Dumont et al., 2000a). Mailhot and Dumont (1999) concluded accordingly that the 1987 management plan had failed to reduce population decline or alter the status of overfishing.

2000: A stronger management plan reducing the commercial catch by 60% in 3 years

In order to be able to maintain the commercial fishery (the sport fishery was of only marginal importance), it was thus necessary to act strongly to adjust the total catch to the potential of the resource. In 1999, a first maximum allowable catch was set at 200 tonnes and split into individual quotas

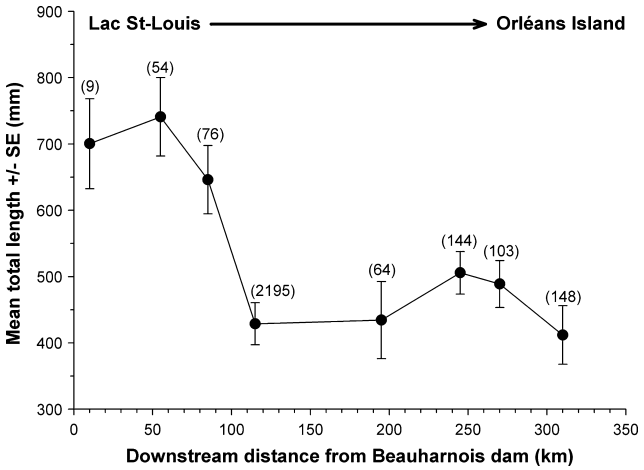

Fig. 3. Average Size (±standard error) of Juvenile Lake Sturgeons in the 1992–1999 Experimental Multi-mesh Gill Net Catch from Beauharnois dam to Orléans Island. Sample size are in brackets (adapted from Dumont et al., 2000b)

according to a breakdown based on past declared catches. To monitor catches and reduce poaching, fishermen also had to tag each sturgeon with a plastic, numbered seal in the boat, before leaving the fishing site. Then, from 2000 to 2002, a much stronger management plan was implemented (Dumont et al., 2000a). Individual quotas were gradually reduced by 20% each year so that, in 2002, the allowable yearly catch had reached a maximum of 80 tonnes (approximately 12 000 fish). The fishing season was also shortened by 2 months and extends now from June 14 to July 31 and from September 14 to October 15. Since 2001, in order to help in understanding the problem observed with systematically sorting larger fish, fishermen must use bar-code plastic tags and bar-coded declaration coupons to declare the individual weight of the tagged carcasses they sell, thereby allowing declared weights to be checked at the wholesaler's facilities.

2009: Where are we now?

Almost 10 years after implementation of the 2000 management plan, the time has come to once again evaluate the status of the stock. Many new sources of information are available and, although it may be too early to state definitely, most of these suggest that the 2000 management plan is working to maintain the current commercial fishery.

- The commercial catch is now much lower and is more easily enforced and controlled due to the tagging of the fish.
- The greatly lowered allowable catch quota is not fully attained. The rate of use of the numbered, bar-coded plastic tags decreased gradually from 97.5% in 2002 to 76.7% in 2008, since the number of the reported catches went from 12 172 to 11 530 during this period. This is not related to the abundance of the resource but is due, rather, to a reduction in fishing effort in some parts of the river, because of the much lower market value of the sturgeon meat (the price paid to the fishermen for medium and large sturgeons decreased respectively by about 35 and 45% from 2001 to 2006).
- From the 1990s to the 2000s, the abundance of juvenile sturgeon increased throughout the St Lawrence River, as revealed by fishery-independent scientific samplings. The sturgeon catch per unit effort increased significantly (doubled) in the important Lac St-Louis fishing sector – in the upstream portion, where the larger fish are concentrated – and the proportion of stations where sturgeons were caught also significantly increased. In three of the four other sectors sampled, the number and weight of sturgeons caught per fishing effort also increased but this increase was not found to be statistically significant (Table 1).
- A regular yearly production of cohorts has been demonstrated at least since the beginning of the 1980s; as well, before and after implementation of the 2000 management plan, one cohort out of three has been a larger one (Dumont et al., 2011).
- Statistical relationships resulting from different analyses illustrate a series of dynamic responses within the St Lawrence River sturgeon production that might be summarized as follows: in the 1990s, larval production on the main spawning ground (Rivière des Prairies) decreased as the previous year's recorded landings increased, and it rose starting in the year 2000 as the previous year's landings began to decrease following the application of a gradually lowered commercial annual harvest quota (Fig. 4). Even

Table 1
Abundance and biomass of lake sturgeons in different sectors of the St Lawrence River caught in the multi-mesh gill net from 1995 to 2008 by the Réseau de suivi ichtyologique (RSI)

					Abundance				Biomass (kg)			
Sector	Year	No of stations	% of stations with sturgeon	P	No of fish	CPUE	P	Standard deviation	Total	BUE	P	Standard deviation
Lac St-Louis	1997	78	34.6	**0.025**	75	0.96	**0.007**	1.79	302.0	3.87	**0.013**	7.35
	2005	72	52.8		159	2.21		3.13	598.1	8.31		11.97
Lac St-Pierre	1995	40	25.0	0.314	21	0.53	0.238	1.30	14.8	0.37	0.253	1.12
Archipelago	2003	64	34.4		71	1.11		2.46	56.4	0.88		2.23
Lac St-Pierre	2002	112	33.9	0.377	109	0.97	0.642	2.00	251.5	2.25	0.708	4.78
	2007	111	39.6		95	0.86		1.52	215.34	1.94		3.87
Bécancour-Batiscan	2001	60	56.7	0.963	106	1.77	0.765	2.76	122.5	2.04	0.843	3.17
	2008	64	56.3		135	2.11		3.21	141.9	2.22		4.01
Grondines-St-Nicolas	1997	37	81.1	0.482	93	2.51	0.560	3.69	83.8	2.27	0.366	5.14
	2006	39	74.3		150	3.85		6.06	149.8	3.84		5.97

Results are expressed in mean number or weight of sturgeon by station (CPUE and BUE). Statistically significant differences between years in a sector are in bold characters.

though it is certainly not the only environmental variable susceptible to influence the recruitment, between 1984 and 2004, a high larval production was noted as a condition favoring the formation of strong year-classes in years of high spring discharge in the Rivière des Prairies spawning ground (Dumont et al., 2011).

The future

As emphasized by Auer (1996), because of the complexity of the system and the simultaneous influence of many factors on the lower St Lawrence River sturgeon population, habitat and harvesting, it will be important to prevent additional fragmentation of this 350-km stretch of fluvial habitat. In the present context, considering the location of the major spawning grounds in the upstream portion of the system, the downstream larval drift to the lower reaches and the size distribution observed among sub-adults and adults in the river, which suggests a downstream / upstream colonization from juvenile to adult stages, the building of a dam somewhere across the St Lawrence would no doubt be the most severe problem this sturgeon population could face, as it would permanently disrupt the life cycle of the population.

The management of this fishery should also be based on the continued application of the current conservation restrictions, control measures, law enforcement and periodic monitoring of the population and commercial catch. In terms of habitat, we should preserve and improve the quality of the known spawning grounds, feeding habitats and deepwater refuges, keep on reducing water pollution in the Great Lakes–St Lawrence River system and further enhance our knowledge of the biology and habitat of this species.

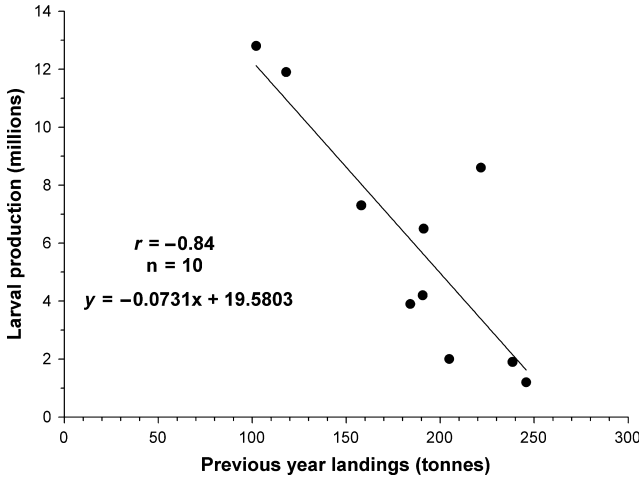

Fig. 4. Relationship Observed between Previous Year Commercial Landings and Larval Production in the Rivière des Prairies Spawning ground from 1994 to 2003

Acknowledgements

This paper is dedicated to Réjean Fortin who died prematurely in 2001. Réjean was an excellent scientist and pedagogue and a great colleague and friend. His contribution to the knowledge of sturgeon biology and management will remain pertinent for future decades. We also want to acknowledge all the biologists, wildlife technicians and commercial fishermen who assisted with various portions of this work.

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